Wright St Univ Participation in AFRL University Engineering Design Challenge

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14. ABSTRACT

The research team was formed in September 2011 as part of the Fall/Winter senior design sequence. Five members were chosen, and these members were asked to sign up for the ME 499 Special Problems class in Spring 2012 in order to ensure their participation in the project for the entire year. In the following year this was not be necessary because WSU transitioned to the semester system. Therefore, in the 2012/2013 academic year and beyond, the team was formed in the Fall semester, and continued the two-semester capstone sequence through the end of the year.
Depending on the nature of the objectives of the competition, the team members were chosen depending on whether they are mechanical engineering majors or materials engineering majors, both of which reside in our department. The progress of the project was tracked using a Gannt chart that was updated as needed. All of the students on the team were required to attend weekly meetings with the faculty advisor to provide the current project status, and to plan the following week's objectives.

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The Wright State AFRL University Design Challenge Team

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Abstract

The United States Air Force has a need to ascend objects in a silent and stealthy manner, without the use of a grappling hook or similar device. To that end they issued a design challenge to a group of universities to have teams of engineering students design and manufacture an alternative design to existing methods. With this goal in mind they outline several objectives; first the design must be able to ascend ninety feet. Second, the design must be inaudible at two hundred feet. Finally, the design must be safe.

With these goals (i.e. design obstacles) in mind the design team at Wright State University has come up with two distinct designs. The first design essentially uses a remote control car to climb the wall. The vehicle is held to the wall using a combination of sticky tread (tank tracks) and pressure differentials, i.e. a vacuum. The second method is a buildable pole, which is comprised of three and half foot sections that collapse to twenty-four inches in length.

This project is important to the United States Air Force because it will provide extra mobility to units that are in urban environments, as well as rough terrain. This is because the solution will provide a method to overcome the obstacles that exist in these environments. In urban environments the main obstacles will be buildings and in rural settings the main obstacles will be cliffs.

The progress of the team has been marked by the completion of the pole, which completed a successful test run at the end of February. The fifth prototype of the robot successfully climbed the wall using a tank-tread mode of movement, while the most recent branch of the vehicle utilizing four-wheels also successfully ascended a testing wall. All three designs will be presented at the competition in order to ensure that an optimum score is achieved.

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Introduction

In August of 2011, the United States Air Force Research Laboratory (AFRL) tasked nineteen schools with the challenge of constructing a climbing assistance system. The initial project description given to the schools by AFRL reads as follows:

> "In some rescue and assault operations, soldiers are required to access locations that require climbing of vertical obstacles in high-risk, non-permissive environments. These soldiers may encounter these obstacles in different types of terrain; wilderness, rural, and urban, which may include cliff sights, rock slabs, buildings, bridges, dwellings, and other man-made facilities. Currently, operators are equipped with ropes, harnesses, grapples and carabineers and are trained in climbing skills including lead climbs, belaying, rope installations, knots, and rappelling. Apart from the physical demands of such climbs, grapples are not effective in many instances due to the lack of a grappling hold, or the long distance needed to throw the grapple/rope is beyond the capability of the troops. What is needed is a system to allow troops, with their equipment, to scale buildings or mountain faces under a variety of conditions, efficiently and effectively. Required capabilities include:

- Ability to accommodate troops and their gear, approximately 300lbs
- Capability to climb rock faces and concrete/adobe walls of 60ft or taller, that are vertical or near vertical – this may be replicated by typical gym climbing walls and firefighter training towers.
- The ability to provide climbing assistance without the need to grapple over the top edge of the structure is desired. These faces may have some structure (fissures, ledges, windows, etc), but the ability to accommodate a variety of conditions is desired.
- Anchor points are possible either by placing "friends" or pitons. Permanent holes in the wall faces are allowed.
- The ability for the device to permit multiple pitches during the climb or to allow use by multiple troops is desired (reusability).
- Rate of climb should be faster than what is done today, or less strenuous than current operations at comparable speeds.
- Minimize the weight of the system that needs to be carried by the operator (s).

- Device/system should be easily carried by a single troop, ideally fitting in an assault/tactical backpack with volume of roughly 20"x10"x8", or attaching to a backpack in a way that allows soldier mobility, or fitting in a larger rucksack with dimensions of approximately 24"x14"x10".
- It is desirable that the system "allows the operator to do other tasks while climbing, including holding and using his weapon, radio or other equipment."

As the project has developed many modifications have been made to the above criteria. Some of these criteria changed the scope of the design project such as changing the climbing height from 60 to 90 feet. Others were minimal such as the explanation of additional criteria for the scoring of the device such as its stealthiness, its ease of use, and its relative weight.

Project Details

The team began with an excess of ideas some of which include: the use of a jet pack, a MAV, a wall-climbing-robot, a lighter than air vehicle, sticky hands, suction-cups, glues/epoxies/gels, a 104 foot pole, a ladder, a launcher, the use of a projectile, modifying existing rounds, the use of small hand holds or steps, and more. From this surplus of ideas, the overall project goal was divided into three main sub-goals: getting up the wall, securing to the wall, and getting an individual up the wall.

From the given design criteria, method of scoring, manufacturability, and feasibility of design and use ideas were systematically eliminated until only four remained. Those were the wall-climbing robot, the pole, the projectile and the ladder. These were evaluated, tested, modeled, prototyped, and pursued until they were either validated or eliminated.

The first to be eliminated was the ladder. The design posed a number of difficulties, and would be very difficult to assemble in a time effective manner. Also, the war fighter's back is constantly exposed to the enemy, with no means of defending himself. Although the war fighter could stop, anchor in, turn and return fire at any time, he is constantly in a vulnerable position. Secondly, it was deemed a strenuous climb for the first war fighter since he would have to climb two rungs, secure himself, assemble the next section, secure it to the wall, release himself and resume climbing.

The second to be eliminated was the projectile. After a project update with AFRL in December of 2011, the project adviser informed the team that this idea was to be eliminated due to safety issues with launching a package 90 feet in the air. In the presentation, AFRL requested that if a powder actuated launching system was being designed, that a comparable launching system be used at the competition to avoid any safety issues. Such a system was to use pneumatic or mechanical force similar to that achieved from the prospective powder actuated system. They further stated that the weight of the powder actuated launcher would be counted in the scoring, not the pneumatic or mechanical launcher. Some members of the team interpreted this as the elimination of the concept based on safety issues and sided with the project adviser in eliminating this design.

The wall-climbing robot was broken into two distinct categories defined by the method of adhesion to the wall. The first was suction; the second was electro-static. The electro-static method used a thin aluminum substrate sandwiched between two layers of Mylar. The aluminum was then charged to a various high voltages (around 6.8 million volts), and placed near the wall. The force of magnetic attraction between the highly charged Mylar- aluminum patch and the grounded wall was significant. The issues with this design arose with the coefficient of friction between the Mylar and the wall, and the large surface area needed to generate the force. While coating the Mylar with various materials enhanced the coefficient of friction, it also increased the separation of the aluminum and the wall therefore decreasing the force of attraction between the two. This issue could potentially be resolved given different materials. The second issue with the electro-static is the large surface area required for it to hold a significant amount of weight. The approximate holding power was estimated to be about 1/2 a pound per 42 square inches. Based on the slow progress of this idea, and the above described issues, the group voted to eliminate this idea and focus its time on the two remaining ideas.

The two ideas that remain are the pole and the suction robot. The pole is composed of sixty, 2-ft section poles, 30 of which half an inner diameter larger than the outer diameter of the remaining 30. This allows the poles to be stored inside one another and reducing the required volume of the load within a pack. These poles are jointed together by means of a spring locking pin.. The stability issues relevant for a 100-feet long pole suggest the need for a controlling mechanism, such as a suction vehicle similar to that of the robot, to aid in the poles control and usage.

This vehicle has since been adapted for ascension without the necessary applied force from the pole, greatly reducing the weight and inconvenience associated with the pole. It utilizes 4 wheels and a rear-axle steering mechanism.

The wall-climbing suction robot is a tank-tread type crawler held to the wall with a low pressure region generated by an impeller taken from a hand-held vacuum cleaner.

Safety

Safety while building

There were three main designs that were actually prototyped and tested in the lab. Each had its own sets of safety precautions that had to be taken. The first was the electrostatic robot which incorporated very high voltage Van de Graff generators and stun guns. To deal with this, the main precaution taken was only working with one hand. This doesn't prevent getting shocked, but if a shock does occur there is no way for it to travel across the heart. Every time an experiment was going on, proper grounding equipment was always handy to discharge everything after the experiment had been completed. Beyond that, just typical lab safety was implemented while working in the woodshop or testing in the lab.

With the pressure robot there were two main concerns while prototyping, the first being electrical shock and the second relating to the fast spinning impeller. The biggest risk of electric shock came from using motors that were striped out of vacuum cleaners. These motors then had exposed wires where there weren't before. Extra care us just taken to not touch or connect the wires. As for the impeller blades, most came with protective housings to keep fingers and other appendages so they couldn't come in contact with the blade. Some didn't, and for those they were clamped down when they were run or properly mounted to an apparatus. Again, beyond this there was just normal lab safety applied.

For the pole, there was no real safety implemented beyond normal lab safety while manufacturing the pole, but while testing there were a few things to look out for. First was that there was no one around that this pole would land on if it were to tip over. At 100 ft, this pole could really hurt someone. Next was with the fact that the pole is a giant conducting rod, so no power lines could be anywhere near where this was being tested in case control was lost and it landed on the power lines. Also this was never tested in a storm in case of lightning. Being aware of what was going on was the biggest thing the people testing did because they could keep themselves in a safe location.

While working on the applicator, box furnaces, pulling machines, and epoxies were used. For the furnaces proper heat protection was used and everything was allowed ample time to cool down before being handled. While working with the Instron pulling machine, the main thing was to wear safety goggles and stand back from the instrument. The specimens were taken to failure and sometimes it was the brick that failed, which could send dust and small rocks flying. Safety with epoxies consisted of researching the epoxies and having the proper cleaning supplies there to clean up the people and the tools being used. The best way to prevent contact with the skin was to use Nitrile gloves. Again, beyond this typical lab safety procedures were conducted.

Safety with the Final Product

The three designs that have been taken through to a final product are the pole, vacuum robot and ascension vehicle. Safety for the pole is comparable to that of the testing used in its prototyping, ie. Remain a safe distance between its usage and power lines, people, and objects.

For the vacuum robot and ascension vehicle, safety with the end product will mostly be the risk of it falling off the wall. To be safe with this the operators and spectators need to stay as far back from the wall as possible. An attached parachute will slow an unexpected rapid decent of the vacuum vehicles

Design and Experimental Procedures

Bench Test: Battery Cells

Purpose:

The purpose of the battery cell bench test had been to confirm the known performance characteristic of off-the-shelf battery cells and to obtain an operating envelope for the selected batteries. A readily obtained Nickel Cadmium battery cell, as it had been supplied with the vacuum motor assembly and a Lithium Polymer battery used in radio controlled models were selected for evaluation.
The Ni-Cd battery was to provide the lower end performance marks as it is known that this battery cell has less than optimum weight, dimension, and power density. A Lithium Polymer cell was expected to

lead the performance boundaries as the aforementioned descriptive features are known to dominate the battery market.

Method:

Each of the two battery cells will be charged to the manufacture specified recharging time, obtaining full charge. The battery pack will then connected the off-the-shelf vacuum motor and bonnet assembly. Two trials will be performed on each battery setup; one under a sealed vacuum and one with the vacuum impeller exposed to a 'no-vacuum' environment (i.e.-pulling no vacuum). The batteries will also be weighed, measured and purchase price recorded for further comparison prior to power consumption testing.

The battery packs will be evaluated based on the output voltage and current when utilized with the impeller and motor assembly in each of the two described scenarios. A voltage divider placed in parallel with the battery and motor will properly step down the voltage and prevent an over current as to not destroy the data acquisition device (DAQ). The power input lead from the battery pack will be placed through an active current transducer (CT); again with the CT output will be fed into the DAQ. Timing the trial runs will be handled by the DAQ's microcontroller as the acquisition interval timer will be fixed to 1000 milliseconds. Signals acquired from the DAQ A/D converter will be fed to a columnar output file to be interpreted using plotting software after each test has been completed.

The fan motor will be placed in its appropriate position, either in vacuum or open air, and secured to the testing bench. Test leads from both the voltage divider and CT will be fed into the appropriate analog inputs on the DAQ microcontroller. Software verification will occur before testing in order to ensure correct lead input and timing interval. The impeller motor will be hardwired in the "on" position after the DAQ software has been initiated. Upon successful startup of the test bench the voltage and current will be probed using an external, non-invasive device to interpret an accurate calibration ratio from the acquired voltage and current digital signals. DAQ will acquire signals until battery is completely drained of power. Power will be turned off from the test stand and the DAQ software will be shut down after battery is drained.

Voltage and current for each run and battery (totaling to four evaluations) will then be plotted and compared to, again, both confirm our expectations and force a battery selection.

Procedure:

1) Charge Battery Packs

2) Weigh and Measure Dimensions of Battery, Record Data

3) Record Battery Cell Cost

4) Setup Test Stand and Connect All Appropriate Leads

5) Verify Leads and Motor Assembly are Secure

6) Deploy DAQ Software to Microcontroller

7) Probe Test Stand for Voltage and Current, Determine Signal Ratio

8) Record Data Until Battery is Drained of Power

9) Save Data Text File
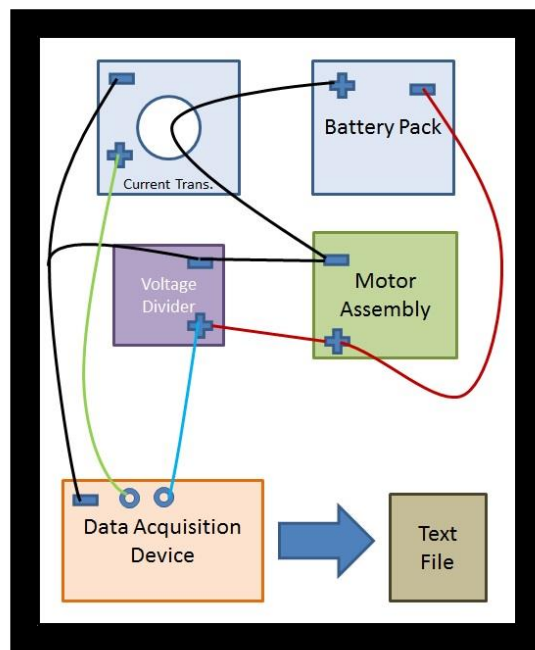
10) Interpreted Results Using Plotting Software
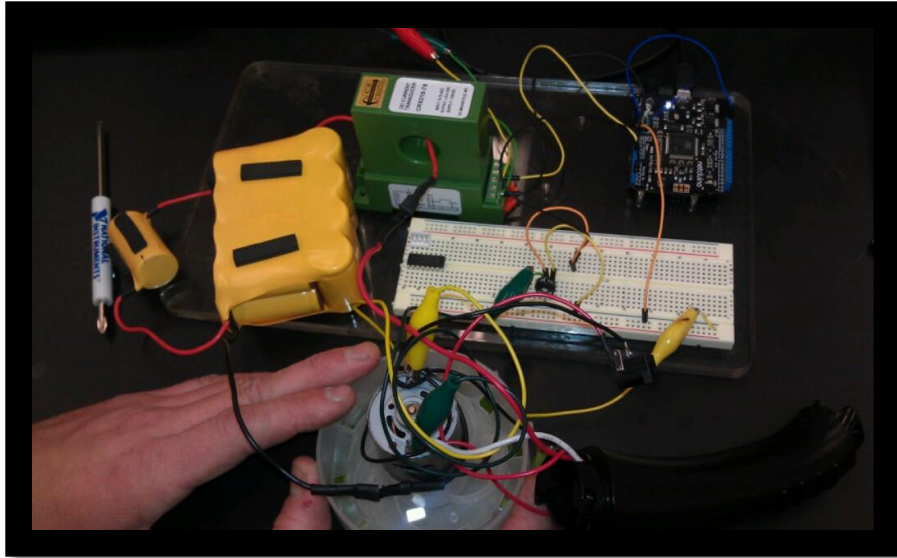

Figure 1: Battery Bench Test Setup Diagram.

Figure 2: Battery Test Stand Setup, actual.

Results:

The Ni-Cd battery pack performed as expected and we were able to determine that at best we would be able to operate the motor assembly for approximately thirteen minutes under vacuum. Assuming that the motor would operate under no vacuum (perhaps intermittently during setup or evaluation) the battery will still provide eight minutes of power to the motor assembly (Figure 3).
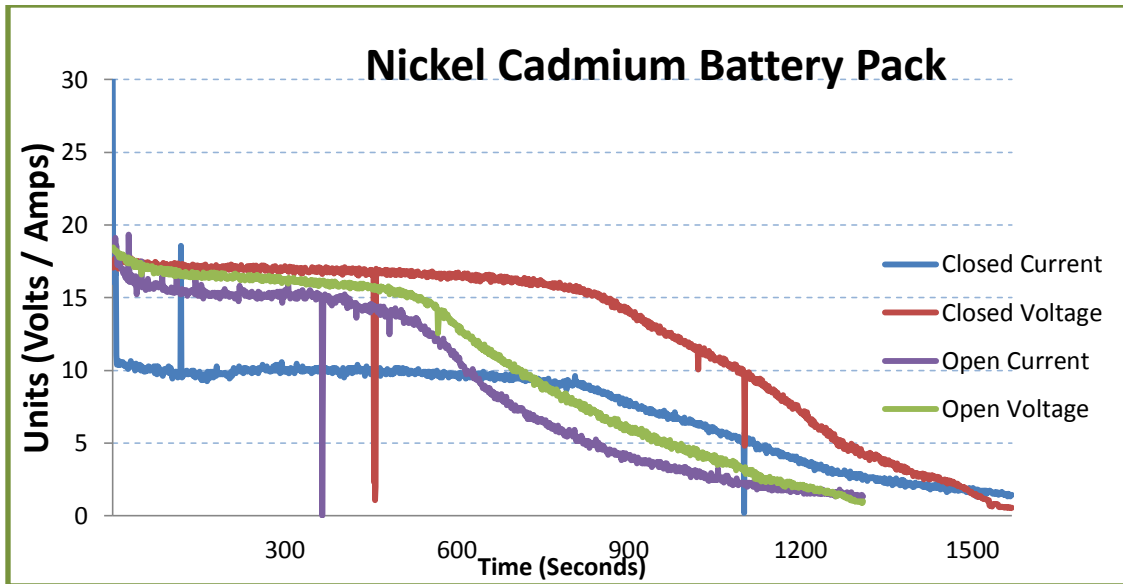
Figure 3: Ni-Cd Results

The Lithium Polymer battery also performed as expected. Operating in vacuum the li-PO battery is able to provide thirty-seven minutes of power. Under circumstance that yield a no-vacuum operation the battery pack provides approximately twenty-three minutes of power (Figure 4).
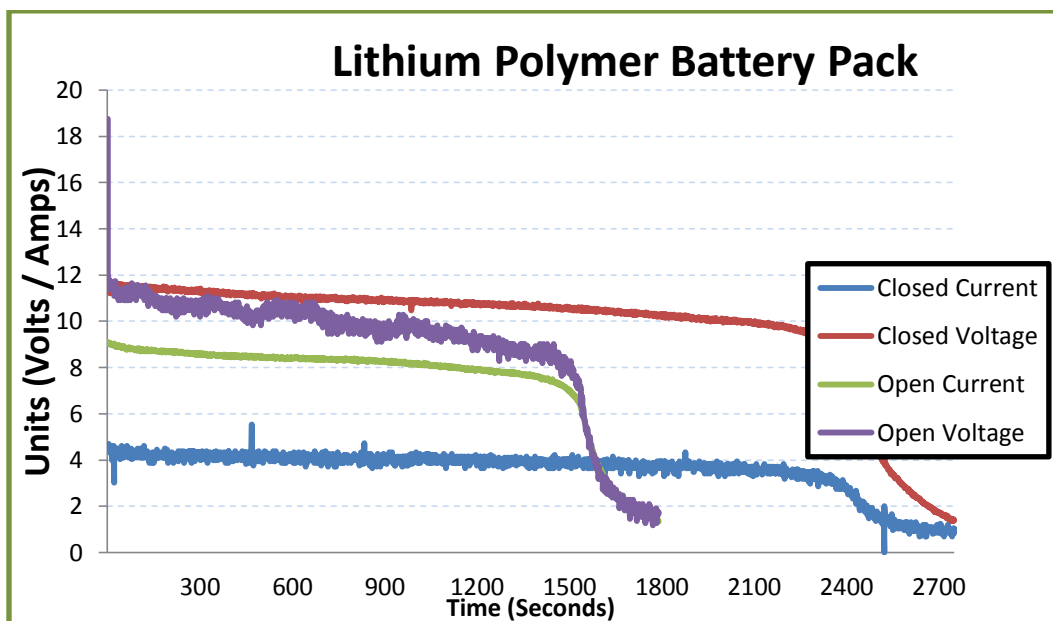

Figure 4: Li-PO Results

It may also be observed that the power density of the Ni-Cd battery is less superior to that of the Lithium-polymer battery cell. In total the Nickel Cadmium battery received only one positive mark in overall cost (Figure ###). However, the specific power density of the Ni-Cd nowhere compares to that of the Lithium polymer cell.

Datum	Units	Ni-Cd	Li-PO	Ni-Cd	Li-PO
Open Run	(min.)	8	25		x
Closed Run	(min.)	13	37		x
Weight	(grams)				x
Volume	(cm³)	263.25	85.313		x

Bench Test: Epoxy and Curing Methods

Purpose:

The purpose of this evaluation is to determine the strength of our selected epoxy when subject to shear loading in the Kevlar patch–masonry block interface. Several testing evolutions permitted incremental understanding of our epoxy such that we could better determine patch size and appropriate heat treatment.

Method:

Evolution one (1) tested the shear force of the epoxy on both a one square inch Kevlar patch and two square inch patch. Twenty minutes of cure time in ambient conditions was then allowed before the patch-epoxy-masonry interface was subject to loading. The strain rate of loading was set at .25 mm / minute and the procedure was allowed to run to failure. Masonry selected for testing was standard clay brick. This set of parameters is to gather an approximate value for the bare minimum performance characteristics of the epoxy.

By selecting two different size patches we hope to correlate patch size with a particular loading amount in order to extrapolate the extent of patch we would require for field use. Also, we chose to allow an air cure for 20 minutes—as this is the manufacturer's recommended dwell period before handling (i.e.- if we can get away without heat treating the epoxy, we would prefer too). The sampling strain rate was fixed to a minimum position in order to get a 'low-ball' strength figure—for the low strain rate allows for the

polymer chains to align and slip more easily. Clay brick was selected as its surface roughness is extremely lower than that of the target obstacle, again contributing to the lower envelope approach of expectations in this evolution.

It is expected that the minimum strength be within the magnitude of the target load of three-hundred pounds. Along with the increase of the area of the testing patch we expect a nominal increase in strength. The samples are predicted to fail in a viscoelastic manner for the epoxy will have limited exposure for cross-linking and the majority of the volume still is in a non-solid state.

The purpose of Evolution two (2) was to determine if heat treating the sample was worth pursuing for the final project design. It is recommended from the manufacturer that we may obtain significantly higher strength with our epoxy if we choose to cure the selected volume at 93°C for approximately 3 minutes. By curing at this temperature we promote epoxy cross-linking at an increased rate when compared to ambient curing. We must also reduce the temperature of the epoxy below its glass transition temperature in order to ensure the majority of the volume has transformed into a solid.

The same patch size for two evaluation sets (one in²) will be utilized and will use a convection heating element to bring the epoxy up to the curing temperature. The convection device will be allowed ten minutes to bring up and hold the epoxy to temperature. In order to obtain a performance envelope we will elect to cool the samples by air and via liquid nitrogen back down below the glass transition temperature (T_g) of 30°C while upon the masonry block sample. Again, we will set the strain rate at .25 mm/ minute.

The convection heating device is expected to gradually bring up the temperature of the epoxy to the curing temperature. Due to the composition of the masonry brick we expect a significant time allotment for the epoxy to cool down below $T_g$during convection cooling. With the liquid nitrogen cooling we expect instantaneous cooling below T_g. Since both evaluations involve bringing up and down the epoxy temperature to the optimum curing and stability ranges we expect similar strength results between the two data sets. By attempting to fully cross-link the epoxy we presume a brittle failure. With the low strain rate we expect our results to reflect the lower spectrum of total strength—as opposed to instantaneous loading. Each specimen will be allowed to run to failure.

Procedure:

    1) Equip Instrom Testing Rig With Mounting equipment

2) Modify Testing Parameters To Reflect Described Methods

3) Apply Epoxy to Kevlar Patch

4) Adhere Patch to Masonry Sample

5) Perform Prescribed Curing Method

6) Run Specimen Through Testing Method

7) Record and Interpret Results

Results:

Evolution one met all expectations. The epoxy, when cured in ambient conditions for twenty minutes, was able to hold 200 pounds in shear along a one square inch cross section. An increase in bonding area also increased the holding strength showing that we may increase patch size to achieve the loading necessary for field use.

Viscoelastic behavior was observed as the epoxy was not fully cross-linked within the Kevlar-Brick laminate. This lack of crosslinking is noted by the rise and fall of the loading-displacement curves. As the ultimate loading of the minimally cross-linked adhesive peaked the patch began to slide along the patch interface—with the loading ability decreased as the adhesive-patch interfaced was destroyed.
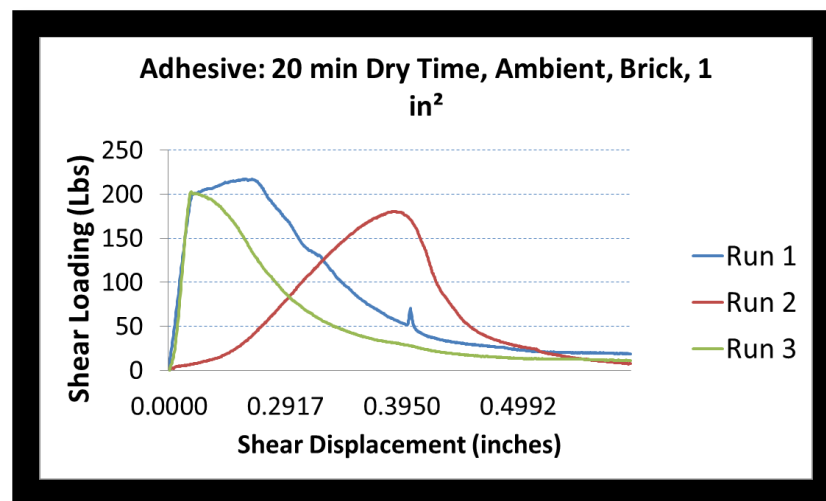

Figure 5: Loading Results from 20 minute ambient cure on one square inch Kevlar patch, brick substrate

Figure 6: Maximum loading and Average for Three Trials of 20 min ambient cure, 1 square inch Kevlar Patch, Brick.

Figures 5 and 6 describe the shear loading and resulting shear displacement for the specified loading scenarios. Figures 7 and 8 are comprised of maximum and average loading testing data at the described conditions.
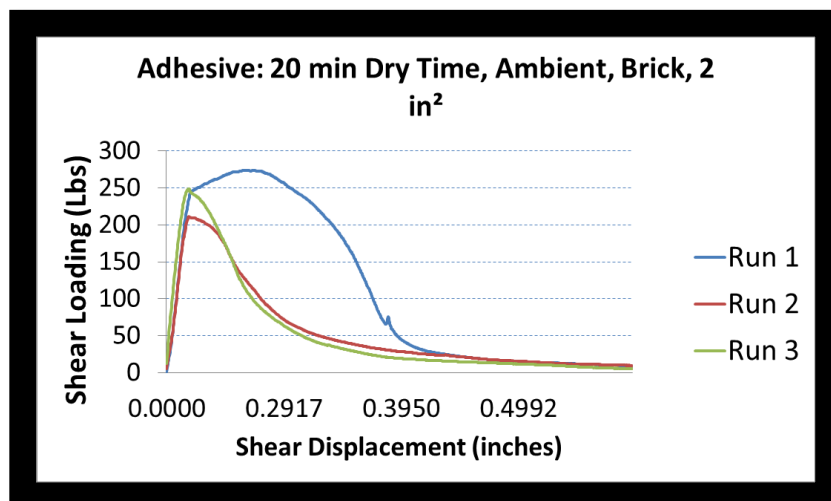

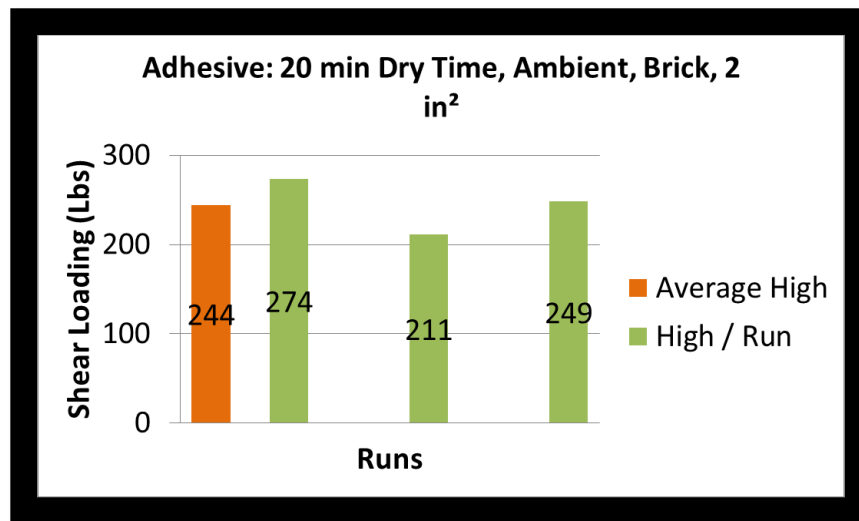**Figure 7: Loading results from 20 min ambient cure on 2 square inch Kevlar Patch, Brick.**

Figure 8: Maximum loading and Average for Three Trials of 20 min ambient cure, 2 square inches Kevlar Patch, Brick

Evolution one confirms that we may achieve the loading strength needed for field use and that we may also increase patch size to tolerate heavier loading. We may also increase the loading ability of the epoxy by promoting cross-linking and eliminating the viscoelastic behavior found with the 20 minute ambient curing conditions.

Results from evolution two also showed promise. It was found that the strength of the one inch patch more than doubled during proper heat treatment. The proliferation in cross-linking was due to the increased curing temperature and ductility was removed via the decrease in operating temperature. Brittle failure may be found in both heat-removal trials as the loading curve peaked and epoxy interface failed without displacement.

It was found in the rapid cool trial that trial #3 failed to cross-link within the magnitude of other trials. This is because heat treatment failed to reach the optimum curing temperature. This result again shows the importance of heat treating the epoxy—as the strength increase is necessary to keep the patch size down.

No extreme differences in epoxy strength between an ambient cool and rapid cool to T_g were observed, thus suggesting suitable strength may be achieved regardless of cooling method.
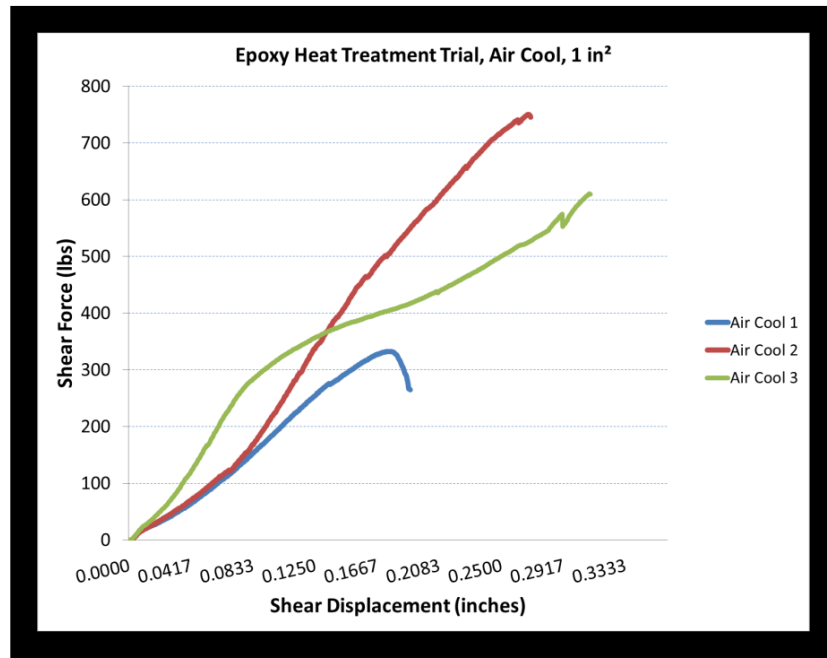
Figure 9: Loading results from 10 min. heat treatment cure on 1 square inch Kevlar Patch, air cool, and concrete
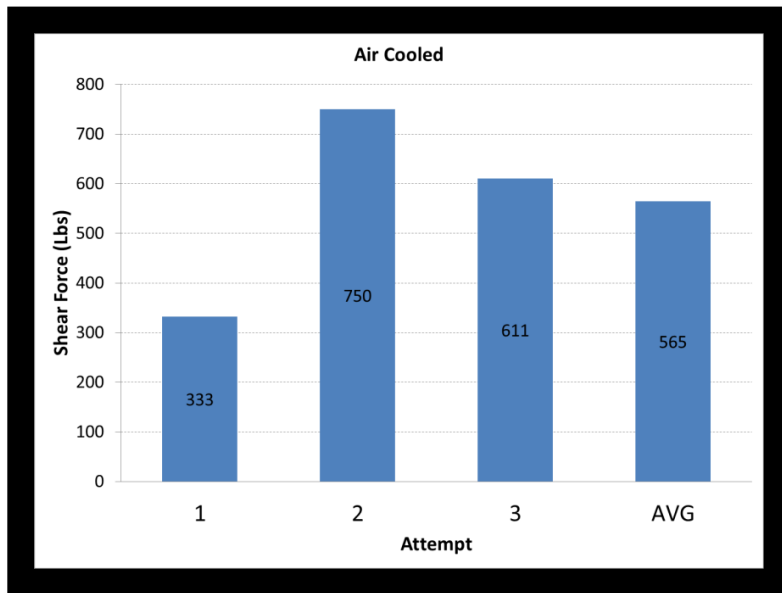

Figure 10: Maximum loading and Average for Three Trials of 10 min heat treatment cure, 1 square inch Kevlar Patch, air cool, and concrete.
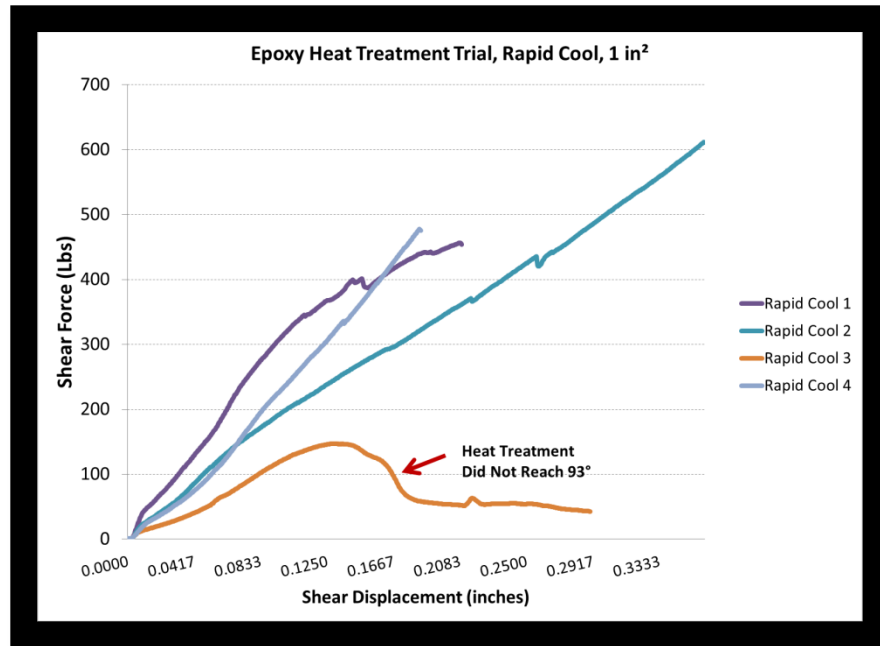
Figure 11: Loading results from 10 min. heat treatment cure on 1 square inch Kevlar Patch, rapid cool, and concrete.
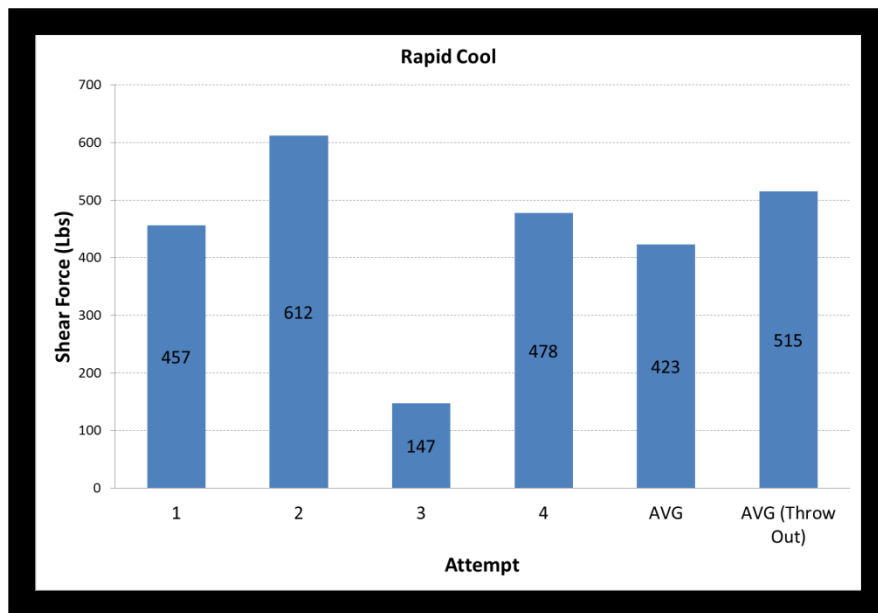

Figure 12: Maximum loading and Average of four Trials of 10 min heat treatment cure, 1 square inch Kevlar Patch, rapid cool, and concrete.

Evolution two confirms that we may achieve nearly double the strength of the Kevlar-Patch interface with a proper heat-treatment. We may also choose any method of removing heat from the patch interface to reach the glass transition temperature—further increasing loading capability and minimizing overall patch size.

Results and Discussion

The lithium-polymer battery has a usable life cycle of 30 minutes. This is the battery that will be integrated into the robot as the main power source. Another battery will be used to provide the wattage for the heat strip to set the epoxy-patch matrix.

The pole, robot, and ascension vehicle will utilize a composite patch of which the fiber matrix is Kevlar and the amorphous matrix epoxy. This patch will be placed on the wall and then will cross-link (cure) as a basis for the wall climbing point. This composite is more than sufficient to hold the weight of the climber with a reasonable factor of safety and the main worry for failure is the substrate (building face) failing. The pole had a successful test assembly against the Wright State Climbing tower. The time that is took was roughly 10 minutes from start to finish and it utilized ten sections of rod, which extend to a length of three and three-quarter feet, end up at a total height of forty feet. This test proved that it was possible to accomplish the goals assigned to the team with this method. The biggest advantage that this method has over the micro-vehicle design is its silence (relatively speaking). Its largest disadvantage is the imprecision and controllability of the entire ninety foot length. Its other disadvantages are weight and volume, as it does not entirely meet all of the criteria laid forth in the project description.

The robot successfully ascended the wall for three feet and then drove back down. It was unable to repeat the attempt because of an axle piece breaking. It should be noted that this piece has since been replaced with a higher quality machined piece, as well as a stronger material. The entire gearing system has been upgraded to orbital gears. The largest advantage that this design has over the pole is the ability to precisely place a patch in a specific location. Its single largest disadvantage is the noise generated by the vacuum that holds it to the wall. A figure of this Robot can be observed below:
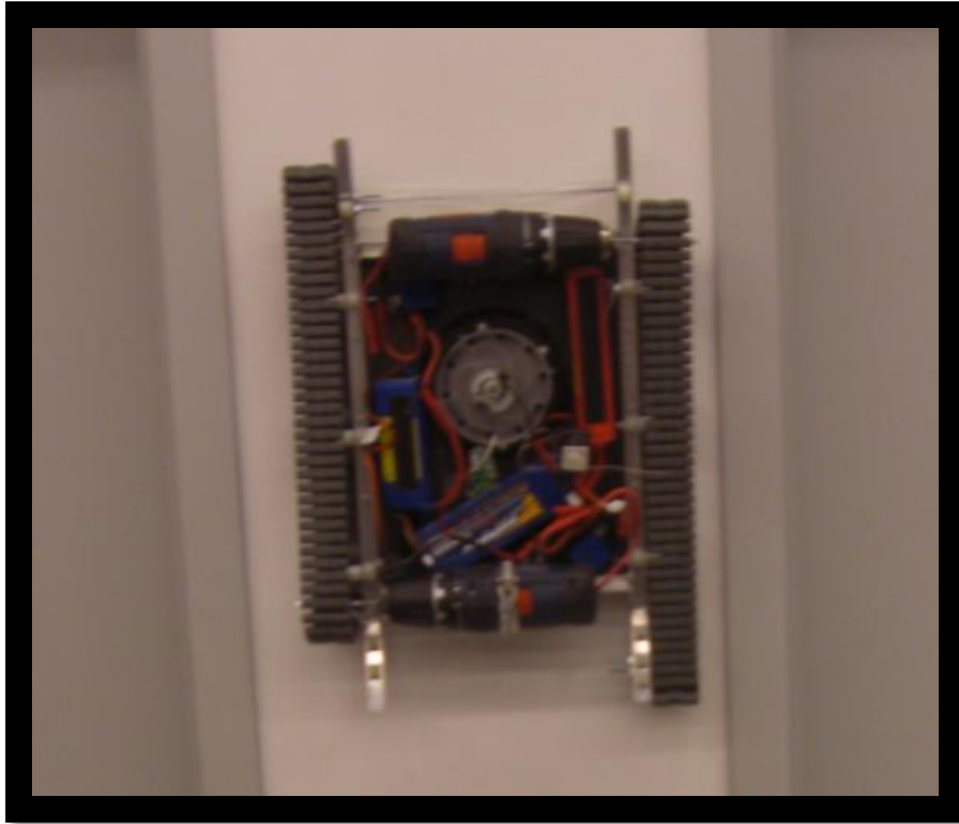
Figure 13: Robot

The vehicle designed to be used in conjunction with the pole proved standalone capabilities. It was able to adhere and climb a wall without the use of the pole by means of suction, four-wheels, and rear-axle steering mechanism. The vehicle utilized servos impeller motor regulation, thus adequately adjust the strength of the vacuum. This feature, in combination with independent wheels as opposed to a track system, is the largest difference between the vehicle and robot designs. The designs are comparable in weight. The robot is a more rugged design, whereas the vehicle can be near-fully disassembled and reassembled onsite for ease of storing and also uses a sound deafening device for the vacuum system. This sound deafening device will, however, be integrated into the Robot system.

The vehicle and robot designs have both conquered heights on the wall upon tested, and all three designs, despite their variations, would be able to accomplish the described task. Upon anchoring by use of the applicator fixed to one of these devices, the provided APA-3 ascender from Atlas Devices will be used to ascend the dropdown line from the anchoring method.

Conclusion

Each design has its advantages and disadvantages. The chosen design however, will be the one that meets all competition criteria, as well as completes the desired task safely, quickly, quietly, and with the least amount of strain on the operators. With that being said, the pole will not be a desirable solution for the competition design. The final design will be chosen for duty upon most consistent demonstrations of usage just prior to the competition date, and will continue to be refined until that date. If the design were to be chosen today, the robot would be favorable choice as a result of its ruggedness and new, improved orbital gearing system.

Appendices

Thermo-Electric Coolers

The design of the patch calls for the use of a thermo-electric cooler. A thermo-electric cooler is also known by another name, a Peltier Junction. Below is a description of the effect found on the website of the manufacturer from whom the team acquired the thermo-electric cooler:

> In 1834, a French watchmaker and part time physicist, Jean Charles Athanase Peltier found that an electrical current would produce heating or cooling at the junction of two dissimilar metals. In 1838 Lenz showed that depending on the direction of current flow, heat could be either removed from a junction to freeze water into ice, or by reversing the current, heat can be generated to melt ice. The heat absorbed or created at the junction is proportional to the electrical current. The proportionality constant is known as the Peltier coefficient.[1]

In other terms, it is a miniature battery powered heat pump, which is one of the basic thermodynamic cycles. This is ideal for the use of the team since first the epoxy patch needs to reach a maintained temperature for a period of time then the heat needs to be removed quickly in order to ensure the full strength of the epoxy.

Discarded Ideas

Electro-Adhesion

An alternative method to the suction for adhering to the vertical surface with a small scale crawler was

electro-static adhesion. This method used high voltage electricity to charge a plate of a thin conductive substrate, which was then insulated by an equally thin nonconductive material. The theory is comparable to that of a capacitor. Since the wall is in electrical contact with the physical ground, it is an endless reserve of electrical charge. By exposing the conductive material to high voltages, an extremely large charge was caused to collect on the surface of the insulating material. As this large charge was placed in increasingly closer proximity to the wall, an opposite charge of a comparable level, and image charge, was induced in the wall. These two highly charged electrical fields were drawn together by the magnetic force of attraction induced between them.

For the purpose of implementing this concept into a small scale vehicle that could climb a vertical surface of an unknown composition, it was decided that aluminum foil could act as the thin conductive substrate, and Mylar could be the insulating material. This was decided in order to allow conformity to various types of surfaces regardless of their composition or surface roughness.

Several tests were conducted using various designs of aluminum between two layers of Mylar. The upper layer is not critical to the design, however it aids in insulating the user from the charge and to a degree, prevents the charge from escaping to the atmosphere. Initial tests yielded results that sufficiently showed that the larger the area of the aluminum, the greater the charge that could be stored in the device.

Multiple methods were used to charge the Mylar - foil - Mylar pad. It was shown that stun guns could provide the necessary charge and voltage to charge the pads however the best results were obtained from using a Vandergraph generator. This is probably due to the consistent direct current flow provided to the pad. The stun guns worked, but were unreliable. This is possibly due to the oscillations used to create alternating current so that the voltage could be increased using a transformer.

The electro-static method proved to adhere to various surfaces. Tests were performed on drywall, brick, and concrete. This method stuck to those surfaces and more while providing enough force to hold more than its own weight. Most testing was performed on a painted concrete block wall.

Whether or not the electro-static adhesive technique could produce sufficient force to support a vertical climbing vehicle with a payload, was not determined. Although the force created by larger pads did increase dynamically as the area increased, it was never determined if a size to weight ratio could be obtained such that the area in contact with the wall would provide enough force to support however large of a vehicle housed that area.

This idea was abandoned due to a popular vote from the team after concerns were expressed about the safety of high voltages, the lack of progress in development, and the feasibility of creating a small lightweight portable Vandergraph generator capable of producing enough charge to support the vehicle. There was preliminary discussion as to implementing this technology into other aspects of the project, such as the stabilizing the pole or applying the Kevlar patch anchor point.

Initially this concept consumed a considerable amount of time as it was a highly promising alternative to the suction for vertical vehicular adhesion, and it did not have the sound issues prevalent with the suction method however nothing further has been done with this concept since its removal from the project.

Parallel Ladder

The ladder concept pursued a field construable ladder that would be able to meet the specifications desired by the customer. There were several major complications with this idea group. The first is the material, which need to be a high strength and light weight material. The second is size, meaning it has to be developed to be small enough to meet the size and weight specifications of the customer.

On the other hand, this idea set is promising because it meets several of the customer's requirements. The first is ease of use, everybody know how to climb a ladder. The second major, and probably the most important requirement, is that is a virtually silent construction. The third quality is that it leaves no trace, i.e. it can be pulled up and disassembled after the obstacle has been ascended.

Materials Strengths

This idea group is focused on ladder design and materials selection. The material must be a high strength light-weight alloy. This prompted the investigation of carbon fiber, which can have the strength properties of steel with the weight of plastic. This combination makes it the material most likely to be selected. Other materials under investigation include various aluminum and nickel alloys. The materials will be rated by potential factor of safety, size, and most importantly weight of entire rig.

Initial Analysis

The initial analysis involved research existing material properties, particularly carbon fiber and running a simple beam deflection on the material. The purpose of the beam deflection is to calculate how much each rung will bend under the weight of the individual climbing the ladder. A sample run of the code is shown below in Figure 4.
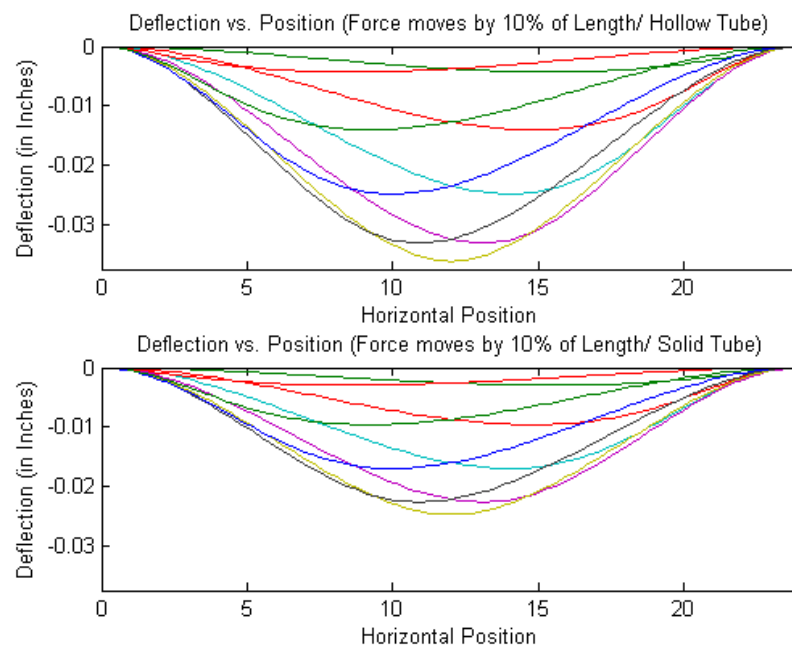

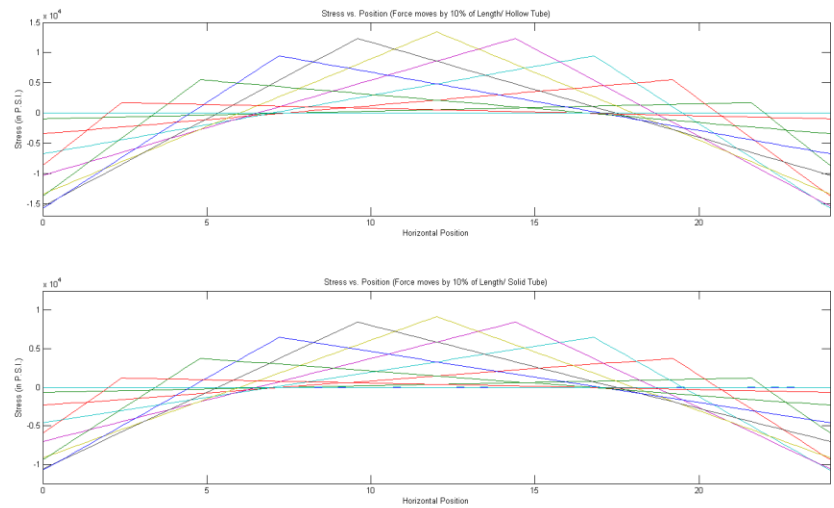Figure 14: Sample Deflection with Carbon Fiber Rung

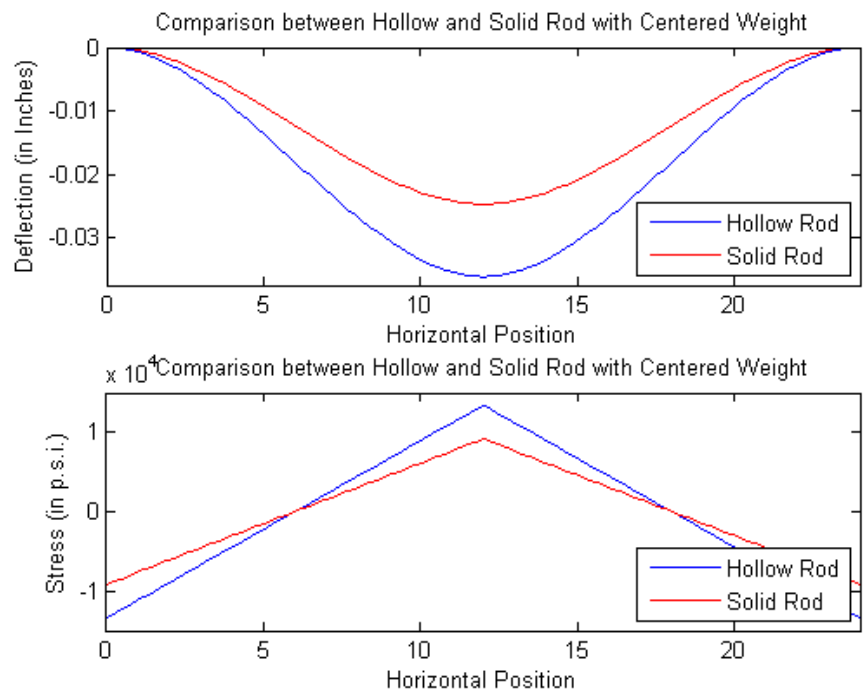Figure 15: Sample Stresses present due to applied force

Figure 16: Sample Comparison between Solid and Hollow Rung

From these simple sample runs, it was obvious that with iterations the rung size and dimensions could be optimized for a given deflection. Another test that will be examined as part of the analysis and will become a graph is an evaluation of the stresses in the material due to the addition of the force. Further analysis must also include a Finite Element Model of the ladder to evaluate buckling, as well as an in depth examination of the hinge points of any model to determine the total stress concentrations at these points.

Solidworks Model

The initial ladder model had been drawn to full working ability in the previously mentioned software Solidworks. The final drawing assembly of the concept is shown below.
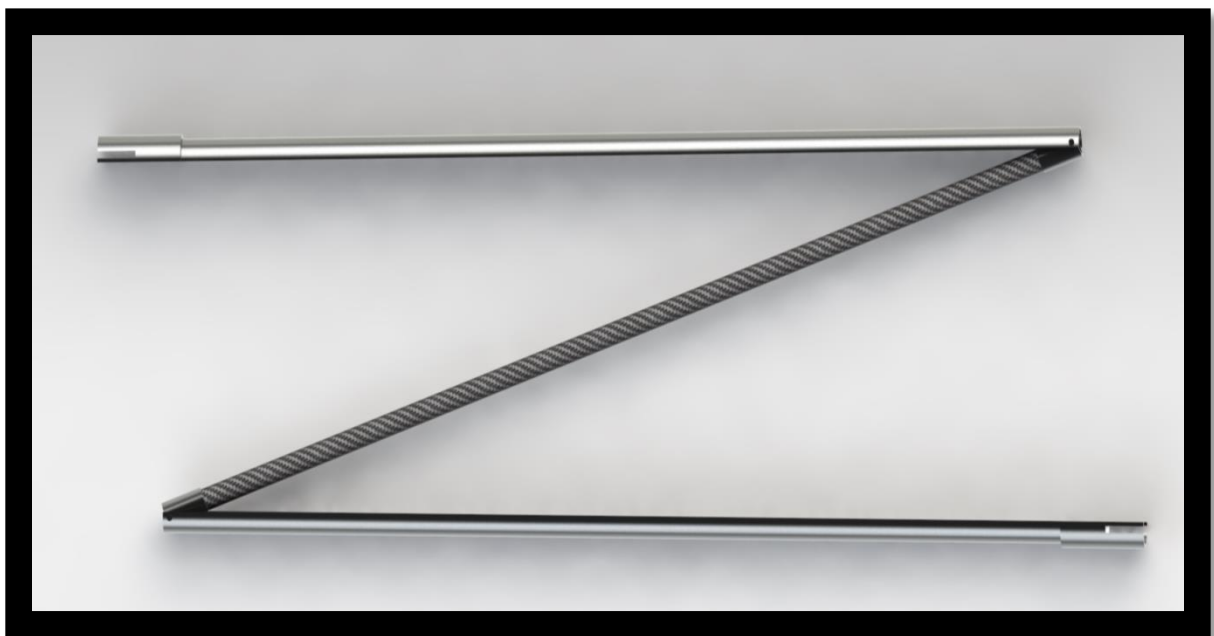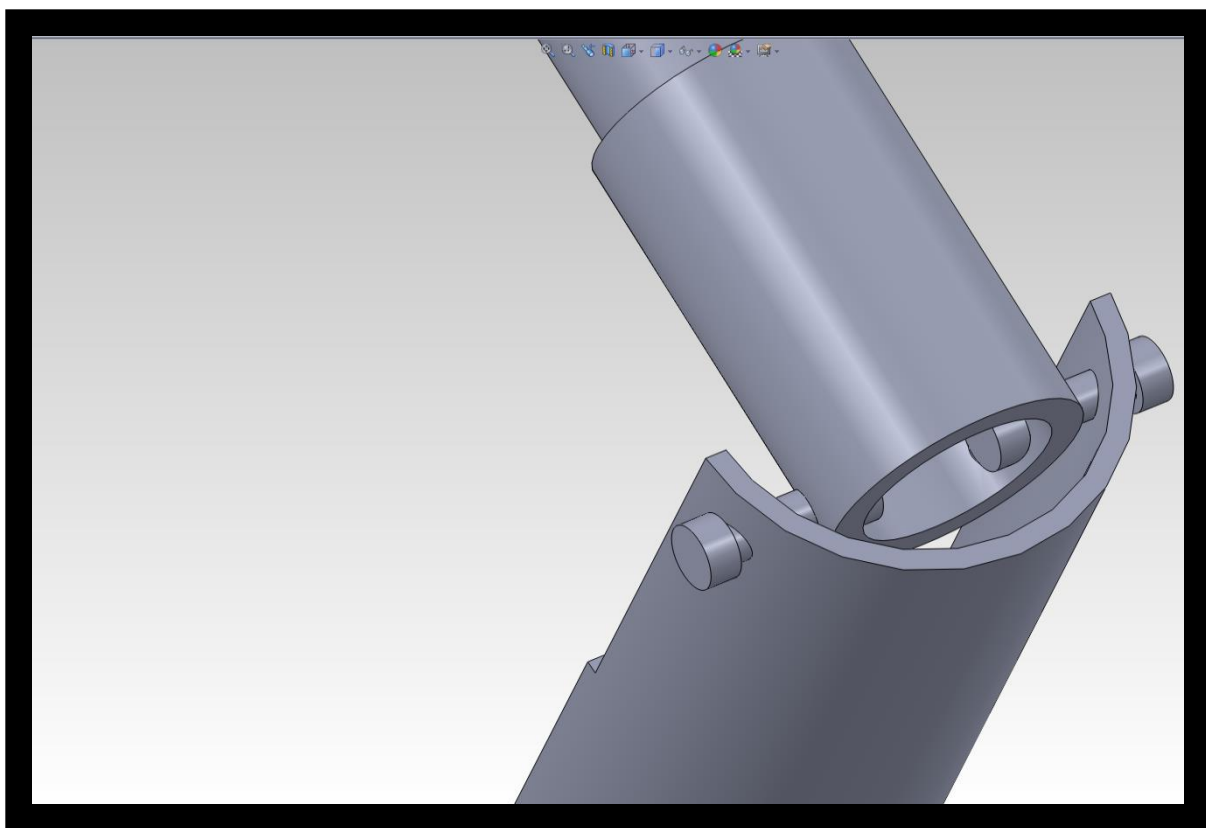

Figure 17: Full Rendered Sample
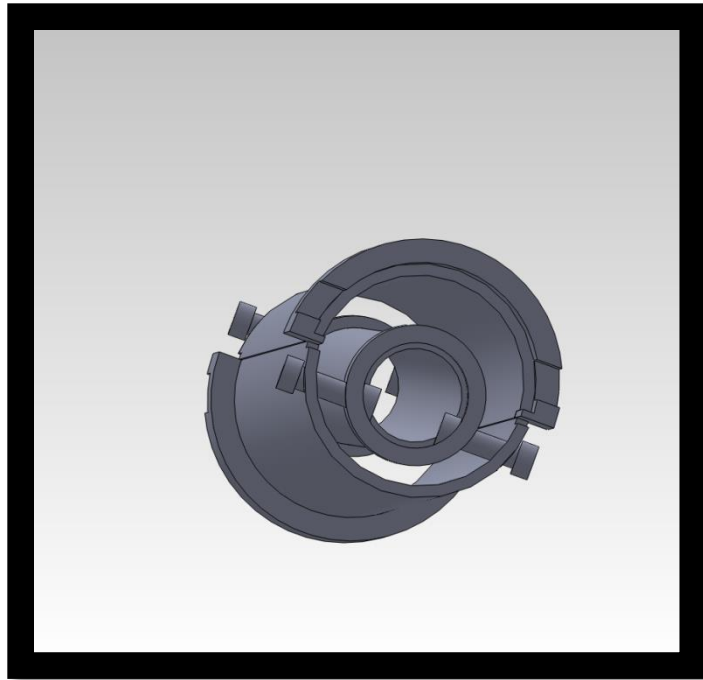
Figure 18: Close-In of Hinge Joint

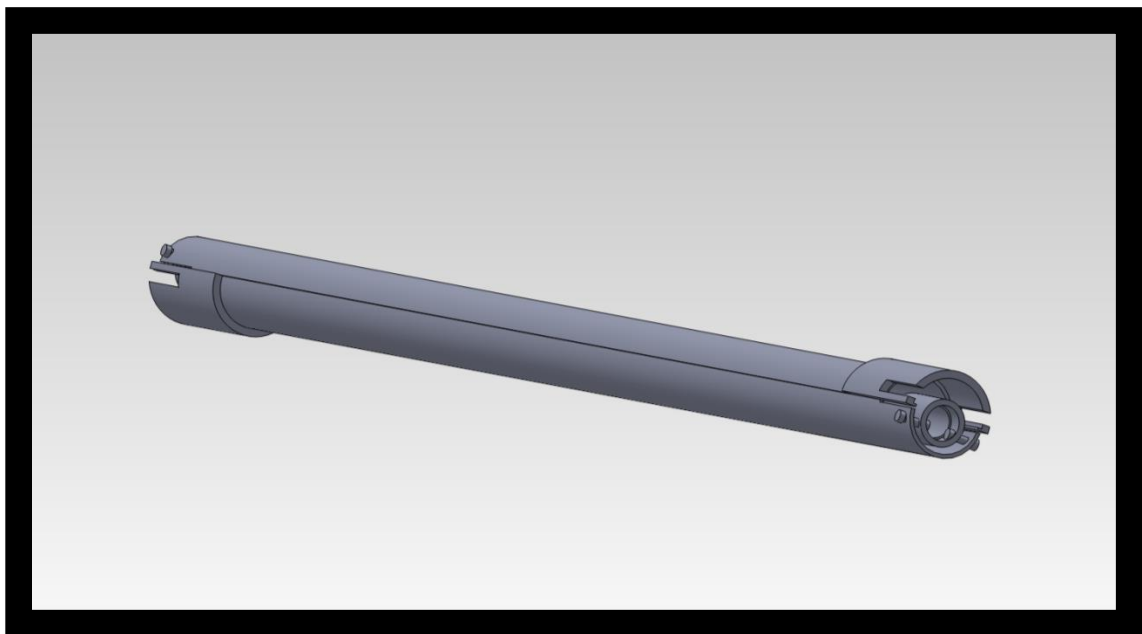**Figure 19: Longitudinal View of Ladder Assembly**

Figure 20: Latitudinal View of Ladder Assembly

From these assembly drawings, the group printed a model using a 3D plastic printer for demonstration purposes. A photo of the printed sample is shown below (note: in order to conserve material the length of the model was scaled down, but everything else remained the same size).

Reasons for Discarding

This ladder had a lot of potential but we ran into a lot of problems. First is that carbon fiber is very hard to work with, especially when drilling holes into it. It essentially just tears up the fibers in the matrix and weakens the material drastically. The second issue is the same that came up with the pole which also had about 50 joints; the combined slop makes the rod act like a limp noodle. The third issue with this design is that the ladder would either sit flush on the wall (making it so the warfighter couldn't obtain a good foot or hand hold), or we would have to engineer more pieces to step out the ladder a few inches from the wall. With all of these things considered, the team decided to nix the idea and pursue more feasible solutions.

Perpendicular Ladder

The perpendicular concept is a subset of the parallel ladder where the team conceptualized using the wall itself as the basis for building the ladder. By having the wall as the basis of the ladder, it would result in the rungs of the ladder folding down and out from the wall. To this end a prototype was created within Solidworks and various FEA simulations were run on it. Some of these results are shown below.
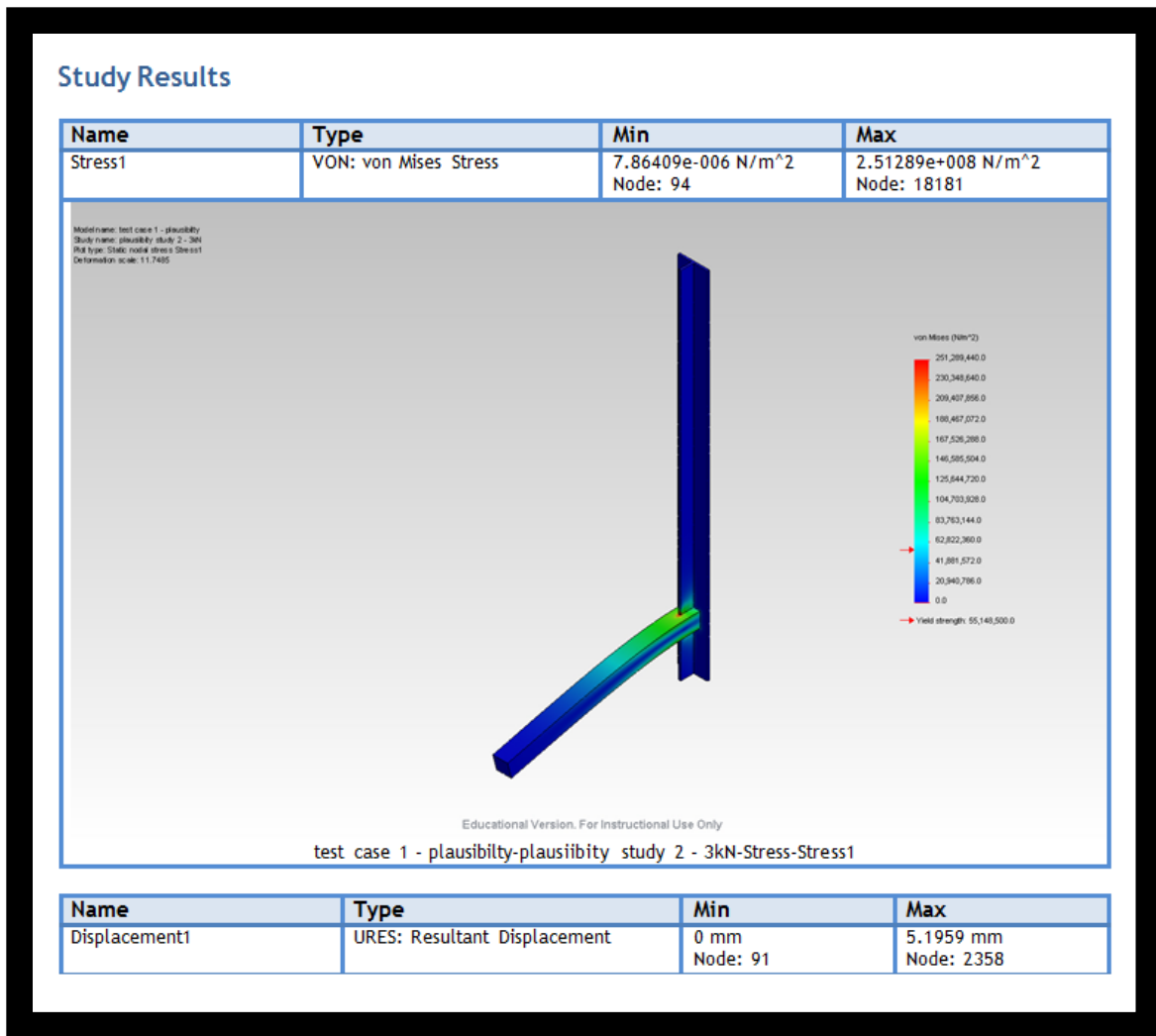
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.86409e-006 N/m^2 Node: 94	2.51289e+008 N/m^2 Node: 18181

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 91	5.1959 mm Node: 2358

Figure 21: FEA Model of Perpendicular Ladder

Reasons for Discarding

This idea was discarded due to safety concerns. It can be noted on the model above the areas of extremely high stress that are nearly ten to twenty times greater than the ultimate strength of the material. If the material was changed to one that had suitable strength, the weight would have exceeded two hundred pounds, making it impractical to tote around a combat situation.

Projectile

The projectile concept was to adapt a 40mm grenade to encapsulate the components necessary to house both an anchoring mechanism and a means to swap out a tethered line with a climbing rope. Initial design criteria sited for use of a civilian 37mm flare gun (much easier to obtain)—and to adapt such a round with the components required to apply such an anchoring method to the obstacle.

Reasons for Discarding

The obvious safety concerns had been forth-right with team staff—encompassing both personal and public safety—with the unknown, yet probable, risk of inducing a campus wide panic. Risk of public and personal safety outweighed any gain meant for this design—in conjunction with the logistics of utilizing a suitable testing site. This design concept was scrapped due primarily due to public safety, as these constraints may not be monitored and predicted by team staff.

Citations

[1] Custom Thermoelectric, Inc. "History of Thermoelectrics : Peltier : Seebeck Effect : CustomThermoelectric.com." *Peltier Coolers : Seebeck Effect : Thermoelectric Cooling : Generator : CustomThermoelectric.com*. Custom Thermoelectric, Inc. Web. 09 Mar. 2012. <http://www.customthermoelectric.com/History.html>.